Backscattering Enhancements from Caustics Produced by Rippled Surfaces

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Grant Number: N000140110095
http://134.121.46.58/Research/acoustics.htm

LONG-TERM GOALS

The goal is to develop and test the hypothesis that certain paths associated with rays reflected from rippled surfaces enhance the backscattering of sound by small targets. The enhancement of the scattering by the small target should be important for targets situated close to a reflection caustic of the rippled surface. This is a “Graduate Traineeship Award in Ocean Acoustics.”

OBJECTIVES

The objective was to detect and model the enhancement as a function of target position including the complicated case of the “two-way” enhancement in which both the target illumination and the detected echo are reflected and focused by caustics.

APPROACH

In previous theoretical, computational, and experimental research [1-4], the fluctuations associated with caustics were studied for acoustic wavefields produced by reflection from rippled surfaces, including the case of a randomly rippled surface. The theory, numerical simulation, and experiments all support the existence of an enhancement in the amplitude received by a hydrophone positioned close to a simple Airy caustic. The amplitude increases with the frequency in proportion to $k^{1/6}$ where the wavenumber k is proportional to the frequency. In the research supported by this grant the acoustic backscattering was measures and modeled for small targets situated in (or near) an Airy caustic. Professor Philip L. Marston directed the research (while receiving no financial support from this grant). Benjamin R. Dzikowicz was a graduate student supported by this grant at Washington State University.

WORK COMPLETED

Ben Dzikowicz completed his Ph. D. Thesis titled "Backscattering of Sound from Targets in an Airy Caustic Formed by a Curved Reflecting Surface." The thesis abstract is listed below under “RESULTS.”

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Backscattering Enhancements from Caustics Produced by Rippled Surfaces**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Physics Department, Washington State University,,Pullman,,WA,99164**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The goal is to develop and test the hypothesis that certain paths associated with rays reflected from rippled surfaces enhance the backscattering of sound by small targets. The enhancement of the scattering by the small target should be important for targets situated close to a reflection caustic of the rippled surface. This is a ???Graduate Traineeship Award in Ocean Acoustics.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

RESULTS

The focusing of the caustic associated with the reflection of a locally curved sea floor or surface affects the scattering of sound by underwater targets. The most elementary caustic formed when sound reflects off a naturally curved surface is an Airy caustic. The case of the spherical target is examined here. With a point source acting also as a receiver, a point target lying in a shadow region returns only one echo directly from the target. When the target is on the Airy caustic, there are two echoes: one path is directly to the target and the other focuses off the curved surface. Echoes may be focused in both directions, the doubly focused case being the largest and the latest echo. With the target in the lit region, these different paths produce multiple echoes. For a finite sized sphere near an Airy caustic, all these echoes are manifest, but they occur at shifted target positions. Echoes of tone bursts reflecting only once overlap and interfere with each other, as do those reflecting twice.

Catastrophe theory is used to analyze the echo amplitudes arising from these overlaps. The echo pressure for single reflections is shown to have a dependence on target position described by an Airy function for both a point and a finite target. With double focusing, this dependence is the square of an Airy function for a point target. With a finite sized target, (as in the experiment) this becomes a hyperbolic umbilic catastrophe integral with symmetric arguments. The arguments of each of these functions are derived from only the relative echo times of a transient pulse. Transient echo times are calculated using a numerical ray finding technique. Experiment confirms the predicted merging of transient echoes in the time domain, as well as the Airy and hyperbolic umbilic diffraction integral amplitudes for a tone burst. This method allows targets to be observed at greater distances in the presence of a focusing surface.

Comment (which is not part of the thesis abstract): While the wavefields associated with hyperbolic umbilic catastrophes had been previously analyzed [4, 5], prior to this research there was no obvious connection between hyperbolic umbilic singularities and the backscattering by small targets situated on (or near) an Airy caustic.

IMPACT/APPLICATIONS

This improved understanding of the effects of focussing on scattering may allow targets to be observed at greater distances in the presence of focusing caused by undulations of the upper sea surface or by variations in the height of the sea bottom. Some of the results also apply to caustics caused by refraction due to ripples in the sea bottom or by refraction due to long-range propagation in water.

TRANSITIONS

After completing and defending his Ph. D. Thesis, Ben Dzikowicz began research in a research staff position at the Naval Coastal Systems Station (Panama City, FL). Among other responsibilities, he is investigating how certain caustics may (or may not) contribute to the backscattering by certain cylindrical targets. Ben now works with Raymond Lim.

REFERENCES

[1] K. L. Williams, J. S. Stroud, and P. L. Marston, "High frequency forward scattering from Gaussian spectrum, pressure release, corrugated surfaces. I: Catastrophe theory modeling," J. Acoust. Soc. Am. 96, 1687-1702 (1994).

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[5] M. G. Brown, “The transient wave fields in the vicinity of the elliptic, hyperbolic, and parabolic umbilic caustics,” J. Acoust. Soc. Am. 79, 1385-1401 (1986).

PUBLICATIONS

Technical report: Ben Dzikowicz, "Backscattering of Sound from Targets in an Airy Caustic Formed by a Curved Reflecting Surface," Ph. D. Thesis (Washington State University, Pullman, WA, 2003) 191 pages.

HONORS/AWARDS/PRIZES

Ben Dzikowicz received the ASA "Best Student Paper in Underwater Acoustics" first place award (spring 2003) for his paper: B. Dzikowicz and P. L. Marston “Doubly-focused echoes from spheres unfold into a hyperbolic umbilic diffraction catastrophe (abstract),” J. Acoust. Soc. Am. 113, 2334 (2003).